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INGER KLINGSPOR

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av
INGER KLINGSPOR
Fil. kand., Mlm

AKADEMISK AVHANDLING

som med vederbörligt tillstånd av matematisk-naturvetenskapliga fakulteten vid universitetet i Lund för avläggande av filosofie doktorsexamen kommer att offentligen försvaras å geografiska institutionens i Lund föreläsningssal tisdagen den 26 oktober 1976 kl. 10.00.

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Several intrusive and extrusive rock complexes in Skåne in southern Sweden have been dated by Rb–Sr and K–Ar age-determination methods. The dated complexes comprise two sets of dolerite dykes, massifs of syenite and plugs of basalt. The basalt necks belong to at least two groups aged 167 ± 4 Ma and 108 ± 3 Ma, respectively (K–Ar). North-west-trending dolerite dykes dated by the K–Ar method yielded an average age of 294 ± 4 Ma. A shale adjacent to a dolerite dyke was studied, in order to ascertain the thermal effect of the dyke on the surrounding argon system. Syenite massifs associated with the tectonic boundary between south-eastern and south-western Sweden have a Rb–Sr isochron age of 1210 ± 38 Ma and an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7055 ± 0.0027 . K–Ar datings of these rocks and their minerals demonstrate extensive argon diffusion, which causes apparent K–Ar ages of 800–900 Ma. NNE-trending dolerite dikes have a Rb–Sr isochron age of 1600 ± 230 Ma at an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7033 ± 0.0015 . The K–Ar ages have been disturbed by the opening of the system and fall in the interval between 800 and 1500 Ma. The syenite massifs contain xenoliths of NNE-trending dolerite and consequently the Rb–Sr age of the syenites defines a minimum age for the dolerites.

Mrs. Inger Klingspor, Swedish Museum of Natural History, Laboratory for Isotope Geology, Fack, S-104 05 Stockholm, Sweden.

The province of Skåne in southern Sweden is rich in volcanic necks, dykes and intrusive massifs of sub-silicic rocks which relate to specific tectonic traits significant in the evolution of the European continent. Two tectonic boundaries of great importance intersect in this area. One is the zone separating central Europe from the Baltic Shield, the other the much older schistosity zone, “the Småland suture”, which is an intra-shield boundary between the entirely different Precambrian terrains of the south-western and central Baltic Shield. The purpose of this investigation was to date some of the sub-silicic rocks, in order to obtain information on the chronology and nature of the geological development of this part of Europe.

Fig. 1 indicates the distribution of rocks in the investigated area. The principal complexes are:

(1) Basalts: Basalt necks in the central part of Skåne.

(2) NW.-striking dolerites: This is a system of numerous fine- to coarse-grained dykes associated with a major, NW.–SE.-trending, fault system traversing central Skåne and with minor WNW.–ESE.-striking dykes farther north. These rocks also comprise melaphyres (Hadding 1916), a

vesicular diabase (Törnebohm & Hennig 1904), a syenite porphyry (Hjelmqvist 1939), and “kullaites” (Hjelmqvist 1930).

(3) Syenites: Massifs or possible dykes of these rocks occur in a schistosity zone in the north-eastern part of Skåne (Fig. 2).

(4) NNE.-striking dolerites, comprising dykes of dolerite, also called “hyperite” (Törnebohm & Hennig 1904), “hyperite diabase” (Hjelmqvist 1934) or “Jotnian diabase” (Magnusson 1960a). These dikes strike N.–S. to NNE.–SSW. and occur in the schistosity zone in north-eastern Skåne and in smaller numbers in the Romeleåsen horst (Fig. 2). These dolerites are sometimes intersected by dykes of fine-grained dolerite striking NNE.–SSW. or NW.–SE.

Fig. 1 conveys a general idea of the relations of the intrusions to various Phanerozoic rocks in the area. A few of the basalt necks pierce the Jurassic strata and are consequently Jurassic or younger. The NW.-striking dykes intersect the Colonius shale, referred to the Silurian (Ludlow), but do not penetrate the Kågeröd formation (Triassic, Keuper) and consequently probably fall into this time interval. The vesicular diabase at Fruålid in-

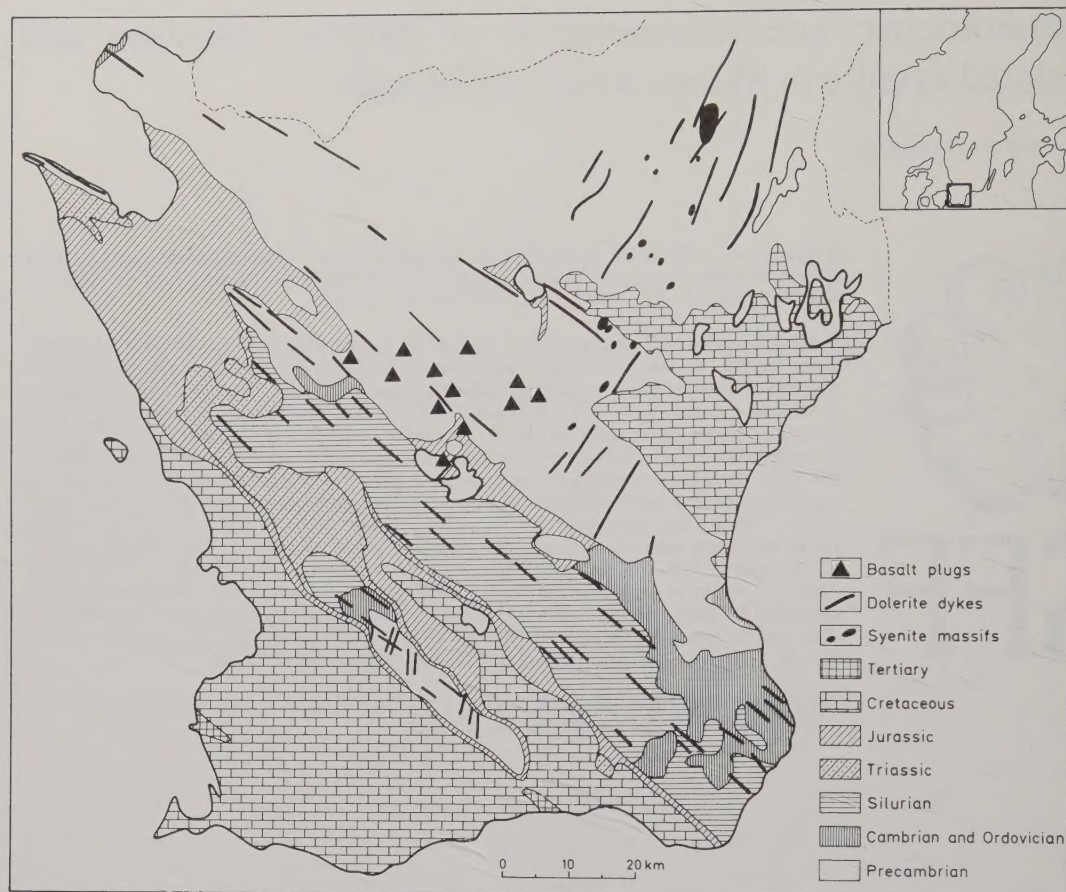


Fig. 1. The geology of Skåne, southern Sweden (after Stanfors *et al.* 1966).

tersects the Upper Silurian Klinta group (Törnebohm & Hennig 1904). The intrusions of the syenites and the NNE-striking dolerites in the schistosity zone extending from north-eastern Skåne to Lake Vänern are possibly connected with the formation of this tectonic belt. Xenoliths of dolerite in syenite indicate the relative ages of these two rock complexes (Hugo Wikman, 1974, pers. comm.).

The age-determinations were made by the K—Ar and the Rb—Sr methods. The number of isotope analyses is 140 for K—Ar and 110 for Rb—Sr. The sample enumeration is in accordance with the inventory of the Laboratory for Isotope Geology at the Swedish Museum of Natural History in Stockholm. The regional sampling pattern is shown in the map (Fig. 3).

A description of the dating technique and the sampled localities is given in an appendix to this thesis obtainable from the author.

Geology and petrography of the investigated rocks

Basalts

Some fifty basalt necks form circular or elongated hills in the Precambrian and Jurassic areas north of Lake Ringsjön in central Skåne. The necks are between 70 and 200 m across. Adjacent plugs sometimes have common eruption pipes (Törnebohm & Hennig 1904).

The rocks are vitrophyric and commonly exhibit columnar structures of mostly 4- to 6-angled pillars (Eichstädt 1882). Due to variations in the cooling and crystallisation of the rock, the pillars sometimes curve from vertical in the neck centres to sub-horizontal at the margins (Törnebohm & Hennig 1904). The pillars at the Rallate locality are partly zoned.

Calcite-filled cracks and zeolite-filled vugs are common in the basalts. There are megascopical

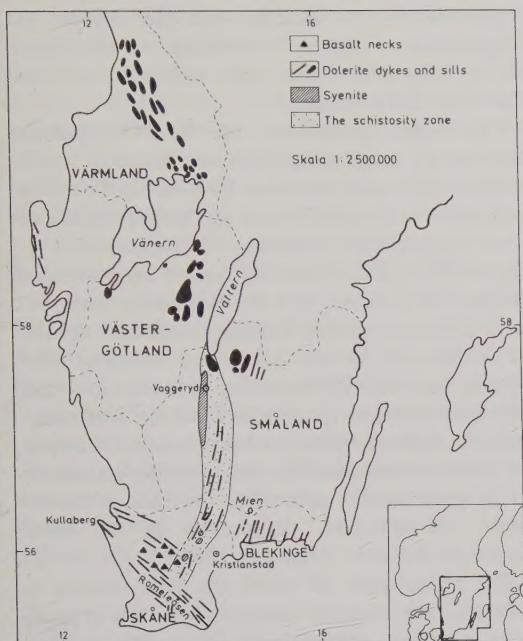


Fig. 2. The schistosity zone and the sub-silicic and associated rocks in the southern part of Sweden.

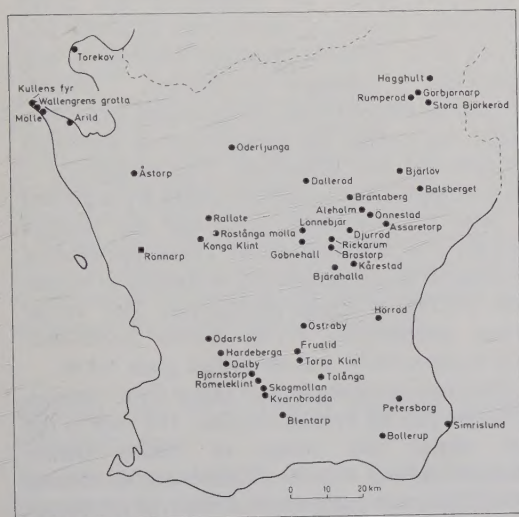


Fig. 3. Sampled localities.

grains of olivine (forsterite). The contents of olivine in the same neck, for example, in the basalt at Göbnehall, are variable.

Microscopical crystals mainly comprise olivine, pyroxene, plagioclase and ore. The main component is a brown glass. The pyroxene is an augite which forms phenocrysts. The olivine grains are

often serpentinized along cracks. The plagioclase consists of small platy needles of labradorite. Accessory and crack-filling calcite and secondary grains of microcline, quartz, biotite, chlorite and apatite appear in small amounts.

Eichstädt (1882), Norin (1933, 1934) and Printzlau (1973) give detailed descriptions of the basalt compositions. The structures and microscopical petrology have been treated by Zirkel (1870). Norin (1934) grouped the basalts into hyaline and hypocrySTALLINE. The basalts of Göbnehall and Lönnebjär were included in the hyalopilitic sub-group of the hyaline basalts. The Rallat basalt belongs to his hypocrySTALLINE and microporphyric basalt groups. Eichstädt (1882) classed the Lönnebjär basalt as dark-glass vitroporphyric and the Göbnehall basalt as vitrocrySTALLINE porphyritic with dark glass.

Törnebohm & Hennig (1904), Hennig (1914), Hadding (1916) and Dorn (1957) suggested a Tertiary basalt age correlated with the basaltic volcanicity in central Europe. Dorn specified the probable age as Lower Eocene. Mesozoic and Tertiary dislocation movements in the area are suggested by Troedsson (1954), Magnusson (1957), Brotzen (1960), Magnusson *et al.* (1963) and Bölau (1966, 1972).

Palaeomagnetic (Bylund 1973) and K–Ar radiometric datings (Printzlau & Larsen 1972, Klingspor 1973) indicate that the age of the basalts is considerably greater than the previously suggested Tertiary.

NW.-striking dykes

The mafic dykes traversing Skåne from north-west to south-east and forming a WNW.–ESE. swarm in the northern part of the province consist of dolerites as well as subordinate melaphyres (p. 198), vesicular diabase (p. 198), syenite porphyry (p. 199), and “kullaites” (p. 198). The dykes generally dip vertically or sub-vertically. The texture of the dolerites is mostly sub-ophitic or ophitic in the sense of Krokström (1932). The width of the dykes varies from 0.5 m to about 100 m. Some of the dykes are exposed only in quarries. Others form ridges, which sometimes reach impressive sizes.

Troedsson (1932), among others, described Skåne as a fracture zone separating the Fennoscandian Precambrian from the sediment-covered lowland in central Europe. De Geer (1887) thought of the dolerites as having been intruded into fractures associated with the faulting. Brotzen (1960) suggests that, commencing from the Palaeozoic, the shield subsided and was thus connected with the central-European sedimentary basins. The nature of the tectonic movements at the

boundary of the Baltic Shield and their causes have been considered by, among others, Voigt (1929), Hadding (1933), Weverinck (1936), Hennig (1914) and Troedsson (1930), who variously envisaged only horizontal or both vertical and horizontal dislocations. Weverinck distinguished pre-Liassic (Variscian) and post-Liassic stages. Contemporaneity of the dolerite dykes and the dislocations was suggested, for example, by Hadding (1922) and Magnusson (1957). According to Troedsson (1930), the dolerite dykes are both older and younger than the faults. Both Saxonian and Variscian ages of the faults are suggested by Bölau (1972). The Saxonian movements are, according to Bölau (1959), related to expansion fractures caused by torsional tension in the marginal areas of the Baltic Shield. Tectonic movements during a long period of time have been demonstrated by studies in the quarry at Dalby (Hjelmqvist 1975), where a fault cuts the NW-trending dolerite dykes. According to Hjelmqvist, this fault is probably of Jurassic age.

A connection with the Lower Permian magmatic activity in the Oslo area of Norway and the Variscian movements in central Europe was maintained by Nathorst (1887), Troedsson (1932, 1942) and Hjelmqvist (1939). A Permian age is also suggested by Magnusson (1957) and Magnusson *et al.* (1963). Magnusson assumes repeated movements during the Mesozoic and probably also the Tertiary. Hjelmqvist (1930, 1931, 1939) suggested that the "kullaites" and the melaphyres were younger than the NW-striking dolerites. As far as the dolerites and melaphyres are concerned, this agrees with views previously expressed by Hadding (1916). A difference in the orientations of NNW-striking melaphyres and NW-striking dolerites was found by Lindström (1960).

The NW-striking dolerites were named "Konga diabases" by Törnebohm (1877). This designation refers to the type locality, Konga Klint (Fig. 3), which contains a quartz-rich dolerite. Hjelmqvist (1939) used the name "quartz diabase".

The NW-striking dolerites are generally coarse-grained. Fine-grained facies appear in chilled margins and narrow dykes. The dyke width varies between 0.5 m and c. 70 m. Nathorst (1885) observed that the dolerites intersecting the gneisses are often more coarse-grained than the dolerites cutting Silurian rocks.

Several of the dykes form elongated ridges, for example, the Bollerup and Petersborg dykes and the Fruaid vesicular diabase. The dykes and their contact relations can be easily studied in numerous quarries. The best quarry exposures are at Hardeberga, Dalby, Rönnarp, Åstorp and Önnestad.

The dolerite at Hörröd and the dolerite at Skogmöllan have deviating directions (NNE.—SSW.) but are still referred to the NW.—SE. dyke system.

The main components of the NW-striking dolerites are plagioclase, pyroxene and ore, which between them make up about 80 % of the rock. The plagioclase is often sericitized and saussuritized and is a labradorite—andesine. Micrographic intergrowths of plagioclase and quartz are common. Antiperthite is found in a few instances. The pyroxene is partly uralitized. Quartz, biotite and apatite are prominent, as are secondary minerals like chlorite, hornblende, serpentine and calcite, which contribute between 10 and 20 % of the total composition. Epidote, zircon, talc, potassium feldspar and albite appear in small amounts. Olivine is present in some of the quartz-free dolerites. Veins of calcite are common, particularly in the more weathered dolerites (Nathorst 1885).

The melaphyres, of which the type locality is Tolånga, are reddish-violet-to-grey, fine-grained rocks carrying amygdaloids filled with calcite, quartz, epidote and chlorite. The best-preserved variety of this rock is called augite porphyrite and occurs as boulders in the Torpa Klint quarry (Hjelmqvist 1939). The melaphyres and augite porphyrites consist of phenocrysts of augite and olivine set in a matrix of brown hornblende, ore, plagioclase (andesine—labradorite), chlorite (sometimes altered to talc), glass, calcite, serpentine, apatite and quartz. The phenocrysts are somewhat serpentinized and chloritized. The plagioclase is saussuritized. The Torpa Klint rocks are described in detail by Hjelmqvist (1939) and the Tolånga melaphyre by Hadding (1916). The composition of a sample of augite porphyrite, according to Hjelmqvist (1939), is augite phenocrysts 39.7 vol.%, olivine phenocrysts 9.3 %, brown hornblende 37.8 %, ores 6.8 % and devitrified glass 6.4 %.

The vesicular diabase, also called Öved diabase, is represented by Fruaid samples. The rock is red and carries vug fillings of calcite, quartz (chalcedony) and chlorite (Törnebohm & Hennig 1904). The main component of this type of diabase is plagioclase (labradorite—andesine 50–70 %). Chlorite, biotite, augite, quartz, calcite and apatite appear in smaller quantities. The red colour of the rock is due to the alteration of magnetite to ferric oxide which forms intergranular and cleavage films (Törnebohm & Hennig 1904). The rock is also described by Hjelmqvist (1934) and Veldi (1951).

"Kullaites" are present at the type locality (Kullaberg) and in the quarry at Dalby. Hjelmqvist (1930, 1931, 1934, 1939) described the "kullaite" at Dalby and compared it to a similar rock at Kullaberg. The rocks are very fine-grained and con-

sist mainly of plagioclase, potassium feldspar and chlorite (delessite). Ore, calcite, augite, epidote and apatite appear in small quantities. Amygdaloids of calcite, delessite, potassium feldspar and epidote are present. The "kullaite" at Kullaberg differs from other "kullaite" in containing some quartz and biotite. The "kullaite" at Kullaberg is red, whereas the Dalby "kullaite" is green with red vesicles. The vesicles are filled with potassium feldspar, epidote, delessite and calcite (Hjelmqvist 1931, 1939).

A single dyke of red syenite porphyry is found in the Torpa Klint quarry (Hjelmqvist 1939). The dyke margins are more fine-grained and darker red than the central part. Somewhat sericitized plagioclase is set in a matrix of potassium feldspar, mostly green, chloritized biotite, ore, calcite, chlorite and sparse apatite. Plagioclase phenocrysts amount to 10.8 % and matrix feldspar to 76.5 %. Biotite makes up 9.2 % and apatite 0.9 % (Hjelmqvist 1939).

Shale

Light-grey Colonus (*Cardiola*) shale occupies a fairly large, elongated area extending NW.—SE. across Skåne (Fig. 1). This shale is the wall rock of most of the NW.-striking dolerite dykes.

Shale samples from Rönnarp and Odarslöv contain typical Silurian (Lower Ludlowian) graptolites (Törnebohm & Hennig 1904). The thickness of the shale is estimated to be about 800 m (Törnebohm & Hennig 1904) or 1000 m (Troedsson 1932). Close to the dolerite contacts, the shale is locally folded, the folds being either younger (for example, at Rönnarp) or older than the dolerites (Lindström 1960).

At the Odarslöv locality the shale is exposed for 110 m around the local, 25-m-wide, dolerite dyke. At Rönnarp, drill-cores permit sampling of the environment of a dolerite dike 65 m in width.

Syenites and NNE.-striking dolerites in the schistosity zone

The Precambrian bedrock in north-eastern Skåne is intersected by dykes of dolerite and massifs or possibly large dykes of syenite, situated in a schistosity zone. These dolerites are described by Hennig (1914), Magnusson (1960a), Lundegårdh *et al.* (1964) and Lundegårdh (1971). The dolerite dykes strike between N.—S. and NNE.—SSW. Younger dolerites, mineralogically of the same type as those of the NW.-striking dykes, cut both the NNE.-striking dolerites and the syenites. There are no exposed contacts between the NNE.-striking dolerites and the syenites, but xenoliths of dolerite in syenite have recently been observed at Görbjörnarp.

According to Magnusson (1960b), the dolerites in the schistosity zone mainly consist of labradorite and hyperstene—augite, besides carrying titanomagnetite, biotite and hornblende. The contacts of the dykes are sharp and the marginal facies is fine-grained or very fine-grained.

The dolerite dykes reach widths of about 100 m. They dip vertically or almost vertically. Magnificent quarry exposures are to be found at Håggshult, Stora Björkeröd and other places.

In several cases, the ophitic or sub-ophitic texture cannot be observed macroscopically. Three of the sampled localities carry a more coarse-grained dolerite than the others. These are Assaretorp, Bjäråhalla and Rumberöd, where the textures are macroscopically sub-ophitic. This also applies to the medium-grained dolerite at Brostorp.

The younger dolerites intersecting the NNE.-striking dolerites at Bjäråhalla, Brostorp and Rumberöd have approximately the same strikes as the NNE.-striking dolerites.

Plagioclase and pyroxene are the most common minerals of the NNE.-striking dolerites in the north-eastern part of Skåne and in the Romeleåsen horst in the southern central part of the province. These two components and their alteration products make up approximately 50 % and 30 % of the rock respectively. The plagioclase is most commonly a labradorite, forming crystals up to 5 mm in length. In exceptional cases, as in Rumberöd, the plagioclase laths can attain lengths of several centimetres. The plagioclase is often pigmented. It is more or less sericitized and saussuritized. Antiperthite is present. The pyroxene is mostly clinopyroxene (augite). It is partly pigmented. The pyroxene is often altered. The common alteration minerals are hornblende, serpentine and chlorite. Biotite and ore minerals generally amount to 5–10 % each. The biotite is somewhat altered to chlorite. Apatite, potassium feldspar, quartz and garnet altogether amount to a few per cent. There are sparse grains of calcite, olivine, sphene and muscovite.

Both the syenites and the dolerites have schistose margins. The mode of occurrence of the syenites is obscured by thick soil cover. Only in the quarry at Önnestad is there an exposed contact towards the Precambrian wall rock. The Önnestad syenite is intersected by a 20-m-wide dolerite dyke striking NW.—SE. A 2-m-wide dyke of NW.-striking dolerite intersects the syenite at Brantaberg.

Lundegårdh *et al.* (1964) and Lundegårdh (1971) provide descriptions of the syenites in the north-eastern part of Skåne. The Vaggeryd syenite (Fig. 2) is described in detail by Asklund (1931) and Quensel (1960). The Vaggeryd syenite mainly consists of quartz, orthoclase perthite, microcline,

microcline perthite, plagioclase, biotite, pyroxene and hornblende. Smaller quantities of sphene, apatite, zircon, garnet, epidote and chlorite occur (Quensel 1960). Magnusson (1960b) suggests that the Vaggeryd syenite was originally and augite-syenite composed of oligoclase, orthoclase, augite and hornblende. According to him, the mineral composition in the central parts of this occurrence has been affected by later autometasomatism, resulting in the formation of sodium-rich plagioclase, aegirine-augite and hastingsite.

The Skåne syenites mainly consist of potassium feldspar (approximately 50–60 %). Plagioclase, quartz and hornblende appear in notable quantities (totalling about 30 %). There are rims of myrmekite. Other constituents are biotite, pyroxene, ore, garnet, zircon, apatite and calcite. The pyroxene is partly uralitized.

Dating methods and procedures

The samples were crushed, ground and split. The 400–630- μ fraction was taken for whole-rock argon extraction. A portion of this fraction was fine-ground for the potassium and rubidium-strontium analyses.

Mineral separations, using fractions in the interval 71–250 μ , often 71–100 μ , were carried out with a Franz Isodynamic Separator. This method was complemented by heavy liquid techniques, using tetrabromoethane with a density of 2.96 g/cm³. Biotite was separated by employing a shaking-table (Faul & Davis 1959). In general, the impurities had no influence on the datings.

A preliminary, X-ray-fluorescence study of the potassium, rubidium, and strontium contents made the selection of samples for analyses easier. The content of potassium was analysed with a Zeiss Spectrophotometer PMQ II with a flame addition, using emission. The sample was dissolved in acids (sulphuric and hydrofluoric acid). Caesium was added to minimize the effect of the ionisation of disturbing elements, such as calcium, magnesium, sodium, iron and aluminium. The method of the chemical preparations was essentially that of Cooper (1963). The concentration was read from a diagram in which the measured intensities of calibrated solutions had been plotted versus the concentrations. This diagram was repeatedly checked by measuring the muscovite standard 68121. The number of potassium analyses was 2–4 per sample. The standard deviation of repeated analyses of K was 1.3 %.

An AEI MS10 mass spectrometer was used for the argon analyses. The mass spectrometer was

connected to an extraction line, a spike reservoir and a pump system. The mass spectrometer was used in the static mode. The mass discrimination was corrected for by continuously checking the isotopic composition of the argon in the atmosphere.

The ratio of ⁸⁷Rb/⁸⁶Sr was measured by repeated X-ray-fluorescence analyses of the sample pressed into pellets. The GSP-1 standard was used, employing the values of Pankhurst (1973), which are 254.7 ppm Rb and 233.1 ppm Sr. The X-ray-fluorescence analyses of the syenite samples 73063 and 73065 were checked by isotope-dilution measurements of the rubidium and strontium contents. The standard deviation of the X-ray-fluorescence analyses of ⁸⁷Rb/⁸⁶Sr is 0.5 %. The ⁸⁷Rb/⁸⁶Sr ratio was analysed in an Atlas CH4 mass spectrometer with an electron multiplier and a Cary amplifier. The digital registering was punched on a tape, which was processed in an IBM 360/70 computer. The standard deviation of the ⁸⁷Sr/⁸⁶Sr ratios is 0.15 %.

A comparison of the potassium analyses of the Bern 4M standard for twelve laboratories shows that the value 8.68 ± 0.2 % K determined at the Stockholm laboratory agrees with the average of the analyses of the other laboratories (8.65 % K).

The standard of the Laboratory for Isotope Geology in Stockholm, 68121, is a muscovite taken from a pegmatite at Risberget in Norrbotten, northern Sweden. Table 1 gives a comparison of analyses of this standard.

Table 1. Standard 68121: comparison of analyses at different laboratories.

	K (%)	Mol ⁴⁰ Ar _{rad} /g · 10 ⁻⁸
Hebeda <i>et al.</i> 1970	8.19	4.10 (⁴⁰ Ar _{rad} =921 · 10 ⁻⁶ cm ³ NTP/g)
Larsen 1972 (pers. comm.)	7.87	3.84
Welin 1976 (pers. comm.)	8.20	4.096

The strontium standard SRM 987 from the NBS in Washington was used for checking the Rb–Sr datings. The value of ⁸⁷Sr/⁸⁶Sr of the NBS standard at the time of dating of the NNE-striking dolerites and syenites was 0.7097, which is somewhat lower than the reported value of the NBS laboratory (0.71014). This error was corrected for.

The following constants were used in the K–Ar calculations:

$$^{40}\text{K}\lambda_e = 5.85 \cdot 10^{-11} \text{ a}^{-1}$$

$$^{40}\text{K}\lambda_\beta = 4.72 \cdot 10^{-10} \text{ a}^{-1}$$

$$^{40}\text{K}/\text{K} = 1.19 \cdot 10^{-4}$$

Table 2. Analytical data from K-Ar dating of the Göbnehall basalt.

Sample	Mineral or rock type, grain size	K, %	$^{40}\text{Ar}_{\text{rad}}$ mol/g $\cdot 10^{-10}$	$^{40}\text{Ar}_{\text{rad}}/^{40}\text{Ar}_{\text{total}}$ %	Age, Ma
71142	Basalt	0.97 ± 0.01	2.47 ± 0.04	80	139 ± 2
71143	Basalt	0.82 ± 0.01	2.52 ± 0.04	78	166 ± 2
71143	Plagioclase, 71–100 μ	0.35 ± 0.01	0.88 ± 0.01	30	134 ± 2
71143	Pyroxene, 71–100 μ	0.11 ± 0.001	0.26 ± 0.001	32	135 ± 2
71144	Basalt	0.65 ± 0.01	1.93 ± 0.03	75	160 ± 2
71145	Basalt	1.10 ± 0.01	3.45 ± 0.05	89	168 ± 2
71145	Plagioclase, 71–100 μ	0.43 ± 0.01	1.12 ± 0.02	31	140 ± 2
71145	Pyroxene, 71–100 μ	0.15 ± 0.002	0.33 ± 0.001	38	119 ± 2
71146	Basalt	1.32 ± 0.02	4.14 ± 0.07	86	169 ± 3
72047	Basalt	0.60 ± 0.01	1.67 ± 0.02	77	149 ± 2
72051	Basalt	1.57 ± 0.02	4.80 ± 0.07	91	163 ± 2

Table 3. K-Ar data for the Lönnebjär (Lö) and the Rallate (Ra) basalt.

Sample and locality	Mineral or rock type, grain size	K, %	$^{40}\text{Ar}_{\text{rad}}$ mol/g $\cdot 10^{-10}$	$^{40}\text{Ar}_{\text{rad}}/^{40}\text{Ar}_{\text{total}}$ %	Age, Ma
71199 Lö	Basalt	1.41 ± 0.02	2.68 ± 0.04	87	104 ± 1
74305 Lö	Basalt	1.43 ± 0.02	2.49 ± 0.04	92	95 ± 1
74305 Lö	Plagioclase, 100–160 μ	0.39 ± 0.005	0.55 ± 0.01	51	79 ± 1
74312 Lö	Basalt	1.31 ± 0.02	2.39 ± 0.03	92	100 ± 1
74314 Lö	Basalt	1.50 ± 0.02	2.52 ± 0.04	92	92 ± 1
71147	Basalt	1.07 ± 0.01	1.98 ± 0.03	86	101 ± 1
71147 Ra	Plagioclase, 100–160 μ	0.21 ± 0.003	0.22 ± 0.001	34	59 ± 2
74291 Ra	Basalt	1.17 ± 0.02	1.78 ± 0.03	86	84 ± 1
74298 Ra	Basalt	1.20 ± 0.02	1.98 ± 0.03	89	90 ± 1
74300 Ra	Basalt	1.03 ± 0.01	1.76 ± 0.03	88	94 ± 1
74302 Ra	Basalt	1.15 ± 0.02	1.83 ± 0.03	85	87 ± 1

The term “model age” is used for the results of single K–Ar analyses. The model ages are calculated according to Dalrymple & Lanphere (1969). The K–Ar isochron ages are calculated according to the procedures of York (1967, 1969). The Rb–Sr isochron calculations followed the method of Williamson (1968). The decay constant $\lambda_{87\text{Rb}} = 1.39 \cdot 10^{-11} \text{ a}^{-1}$ was used.

Dating results and their significance

The basalt necks

Basalts from the three localities Göbnehall, Lönnebjär and Rallate were dated by the K–Ar method. Most of the 16 datings were made on whole

rock. Plagioclase and pyroxene from samples 71143 and 71145 of the Göbnehall basalt were dated separately, as was plagioclase from samples 71147 Rallate and 74305 Lönnebjär. The results are given in Tables 2 and 3 and by the isochron diagrams (Figs. 4 and 5). Fig. 6 shows histograms of the data.

The samples from the basalt at Göbnehall form a good isochron with the age $167 \pm 4 \text{ Ma}$ when the value of mol $^{40}\text{Ar}_{\text{rad}}/\text{g}$ is plotted against the percentage of potassium. The very low contents of both potassium and radiogenic argon make the spread along the co-ordinate axes limited. The scatter of points is small.

The samples from the basalts at Lönnebjär and Rallate are distributed along a reference line of 108 Ma. The similarity of the potassium content in the

various samples taken from the same neck produces also in this case a limited spread of the points along the reference line. In order to obtain a larger variation, two plagioclases were separated and dated. The scatter around the reference line is larger than for the Göbnehall isochron and an isochron age cannot be calculated. The investigation, however, suggests that the Lönnebjär and the Rallate basalts are younger than the Göbnehall basalt. The reference line cuts the y-axis below the origo, which suggests a loss of argon. The 108-Ma age must thus be regarded as a minimum age.

The result indicates that there are at least two generations of basalt necks in Skåne. A thorough investigation of a great number of plugs appears necessary, in order to obtain a detailed reconstruction of the course of events. Semi-continuous eruption of basalts during a fairly long time, 60 Ma or even longer, is possible. The pre-existent necks may have been disturbed by the formation of later necks in a geographically rather limited area. This model, however, has not been tested by the present investigation, because the differences in the ages may be due to argon loss from the Rallate and Lönnebjär necks.

Apparent co-evity of the basalt eruptions with the formation of the rhyolitic rock at Lake Mien (Fig. 2), which has an age of 110–120 Ma (Welin 1975), is an interesting feature. However, Welin's study also suggests that the Lake Mien rock was formed by meteorite impact melting of a mixture of country-rock lithologies. It may thus be non-volcanic.

The regional division of the area of basalt necks into an older, eastern and a younger, western-central part (Printzlau & Larsen 1972) is contradicted by the new results. Lönnebjär and Göbnehall are situated very close to each other and both of them are in the east.

Printzlau & Larsen's K–Ar datings (1972) yielded results which differ considerably from those of the present investigation. Their single sample of the Göbnehall basalt yield an age of 131 ± 8 Ma, which is much less than the age calculated from the isochron in this work. An age of 80 Ma was obtained by Larsen (1975, pers. comm.) for the Rallate basalt. His dating of the Lönnebjär basalt, 120 ± 3 Ma, agrees satisfactorily with the 108-Ma age indicated by the present investigation.

Printzlau (1973) suggests that the glass contents of the rocks are a possible explanation of apparent low ages. Nevertheless, the contents of glass in the present samples from Göbnehall are 30–40 %, which obviously does not lower the ages. The glass contents of the Rallate and Lönnebjär basalts are about 40 and 40–50 % respectively.

Low or uncertain capacities for the retention of

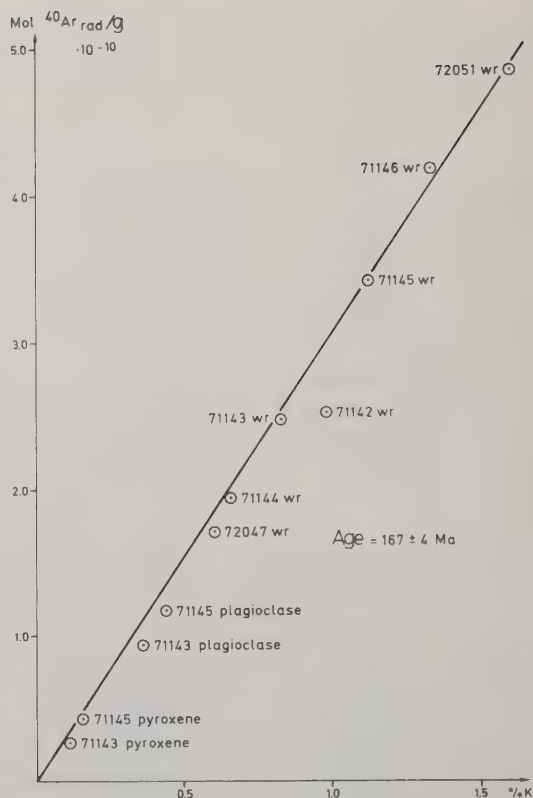


Fig. 4. K–Ar isochron diagram for the Göbnehall basalt. Intercept: -0.09 . wr = whole rock.

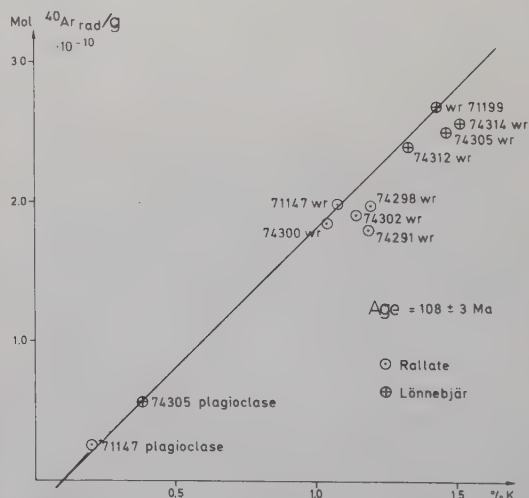


Fig. 5. K–Ar diagram for the Rallate and Lönnebjär basalt. Intercept: -0.19 . wr = whole rock.

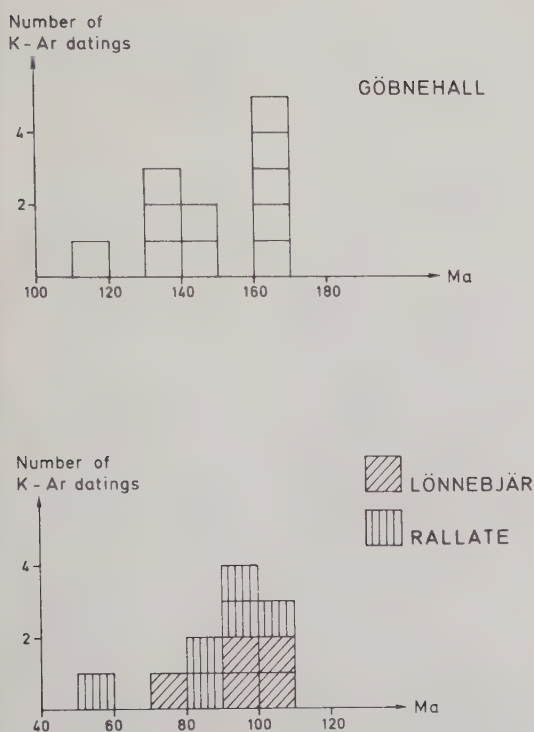


Fig. 6. The basalt data shown in a histogram.

radiogenic argon in devitrified glass have been demonstrated by McDougall (1961), Schaeffer & Zähringer (1966), Dalrymple & Lanphere (1969), and Mankinen & Dalrymple (1972). The latter also stress that other common basalt minerals, such as zeolites, most feldspathoids and clay minerals, are poor argon-retainers. Fresh glass does not disturb the K-Ar datings (McDougall 1966, Armstrong 1966). The glass contains a high proportion of the total potassium contents of the rock (Printzlau 1973).

Some minerals are known to give consistently higher ages than others. Thus, plagioclase and pyroxene, while having quite different crystal structures, are both good argon retainers or accumulators (McDougall 1961, Armstrong 1966). Pyroxenes and plagioclases from several of the Skåne basalts and dolerites have been dated in the present study. Both minerals have relatively low potassium contents (0.1–0.2 and 0.2–1.3 % K, respectively) but are present in large amounts. Pyroxenes are not generally suitable for K-Ar dating, owing to their low potassium contents and the frequent occurrence of excess argon (Dalrymple & Lanphere 1969, Hayatsu & Carmichael 1970). Nevertheless, in this study the pyroxene ages are in several cases lower than the whole-rock ages. In

general, there is good agreement between pyroxene and whole-rock datings and no signs of excess argon have been noted.

No dependable fossil datings can be related to the ages of the dolerites and basalts in Skåne. The conifer *Cedroxylon*, which has been found in a Skåne basalt tuff (Törnebohm & Hennig 1904), was first believed to be specifically Tertiary. However, Dorn (1957), Printzlau & Larsen (1972), Printzlau (1973), and Tralau (1973) have described this fossil from strata as old as the Jurassic. A palaeobotanical study by Tralau (1973) of a basalt tuff in Skåne, associated with the basalt eruption, suggests a Middle or Lower Jurassic age.

In the central part of the basalt neck at GÖBNEHALL, an intrusion of basalt is observed which is younger than the main neck-rock. Samples from this younger segment (71144 and 71145) do not yield significantly lower ages. The two eruptions thus appear to have occurred at approximately the same time. The isochron indicates that the relatively younger intrusion has caused no argon losses from the rest of the basalt plug.

A Jurassic age for some of the basalts is indicated by palaeomagnetic datings (Bylund 1973). A possible Cretaceous age of the Lönnebjär and the Rallate basalts (108 Ma) agrees with Printzlau & Larsen's results. Their datings, however, were made on single samples only and moreover their Cretaceous ages do not derive from the same necks as those which yielded Cretaceous ages in this investigation.

Jurassic volcanic activity, with eruption of olivine basalts, has recently been found in the North Sea (Howitt *et al.* 1976).

NW-striking dolerites, melaphyres, vesicular diabase and "kullaites"

A large number of K-Ar age-determinations have been performed on dolerites from the NW.-SE.-striking dyke system. Forty-nine of the 60 determinations (Table 4) are whole-rock dates. The remainder are determinations of plagioclase, pyroxene and biotite. The analyses of the NW-striking dolerites show a great spread in the diagram (Fig. 7). A closer study shows that great model ages of 306–416 Ma almost exclusively represent dykes which intrude Precambrian rocks. Samples of these dykes have been taken at Brantaberg, Brostorp, Dalleröd, Mölle, Oderljunga, Skogmöllan, Torekov, Åstorp and Önnestad (Fig. 3). Lower model ages are obtained from samples of dykes within the Precambrian horsts of Romeleåsen and Kullaberg. These horsts belong to the north-westerly fault

Table 4. K-Ar data for dolerites and associated rocks in the NW.-SE. dyke system.

Sample and locality	Type of rock	Mineral concentrate and grain size	K, %	$^{40}\text{Ar}_{\text{rad}}$ mol/g $\cdot 10^{-10}$	$^{40}\text{Ar}_{\text{rad}}/^{40}\text{Ar}_{\text{total}}$ %	Age, Ma
<i>Dykes intersecting the Precambrian</i>						
71149 Dalby	Dolerite	Plagioclase, 71–100 μ	0.35 ± 0.01	1.90 ± 0.003	87	284 ± 4
71150 Dalby	Dolerite		0.40 ± 0.01	2.19 ± 0.03	83	286 ± 4
71150 Dalby	Dolerite		0.59 ± 0.01	2.82 ± 0.04	91	252 ± 4
71151 Dalby	Dolerite		0.51 ± 0.01	2.75 ± 0.04	89	281 ± 4
71152 Dalby	Dolerite	Biotite, 250–400 μ	1.11 ± 0.01	5.63 ± 0.08	90	264 ± 4
71153 Torpa Klint	Dolerite		0.76 ± 0.01	4.50 ± 0.06	91	306 ± 5
71154 Torpa Klint	Melaphyre		1.16 ± 0.01	6.05 ± 0.08	89	274 ± 4
71155 Torpa Klint	Dolerite		0.98 ± 0.01	5.36 ± 0.07	84	285 ± 4
71157 Torpa Klint	Syenite porphyry		5.00 ± 0.06	21.65 ± 0.32	93	229 ± 3
71157 Torpa Klint	Syenite porphyry		3.55 ± 0.05	20.07 ± 0.29	93	293 ± 4
71159 Torpa Klint	Melaphyre		1.52 ± 0.02	7.23 ± 0.10	92	250 ± 4
71201 Dalleröd	Dolerite		1.03 ± 0.01	7.93 ± 0.11	86	390 ± 5
72001 Åstorp	Dolerite	Plagioclase, 71–100 μ	0.64 ± 0.01	4.28 ± 0.06	85	343 ± 5
72004 Åstorp	Dolerite		0.46 ± 0.01	2.81 ± 0.04	89	312 ± 4
72004 Åstorp	Dolerite		0.48 ± 0.01	2.53 ± 0.04	86	275 ± 4
72004 Åstorp	Dolerite		0.25 ± 0.003	1.33 ± 0.03	81	296 ± 4
72013 Arild	Diabase porphyrite	"Kullaite"	0.66 ± 0.01	3.60 ± 0.05	79	284 ± 4
72019 Kullens fyr	Dolerite		1.58 ± 0.02	8.71 ± 0.13	86	287 ± 4
72020 Wallengrens grotta	Dolerite		4.94 ± 0.06	23.60 ± 0.35	94	251 ± 4
72022 Mölle	Dolerite		1.00 ± 0.01	6.09 ± 0.08	91	313 ± 4
72032 Kvarnbrodda	Dolerite		0.43 ± 0.01	2.39 ± 0.03	79	291 ± 4
72033 Skogmöllan	Dolerite		0.74 ± 0.01	5.12 ± 0.07	92	354 ± 5
72035 Hörröd	Dolerite		1.13 ± 0.01	5.97 ± 0.08	87	276 ± 4
72037 Hörröd	Dolerite		1.07 ± 0.01	5.96 ± 0.08	93	290 ± 4
72040 Brantaberg	Dolerite		0.89 ± 0.01	7.40 ± 0.11	87	416 ± 6
72055 Torpa Klint	Augite porphyrite		0.75 ± 0.01	3.49 ± 0.05	84	244 ± 3
72060 Dalby	"Kullaite"		1.93 ± 0.03	10.57 ± 0.16	93	284 ± 4
72197 Brostorp	Dolerite		1.16 ± 0.01	6.67 ± 0.09	87	297 ± 4
72202 Önnestad	Dolerite		0.82 ± 0.01	5.07 ± 0.07	87	318 ± 5
72202 Önnestad	Dolerite		1.23 ± 0.02	6.40 ± 0.10	87	272 ± 4
73010 Oderljunga	Dolerite		1.77 ± 0.02	11.82 ± 0.17	92	342 ± 5
<i>Dykes intersecting the Palaeozoicum</i>						
71132 Hardeberga	Dolerite	Plagioclase, 71–100 μ	0.46 ± 0.01	2.64 ± 0.04	89	295 ± 4
71132 Hardeberga	Dolerite		0.50 ± 0.01	1.95 ± 0.03	83	209 ± 3
71132 Hardeberga	Dolerite		0.21 ± 0.003	0.77 ± 0.01	67	195 ± 3
71133 Hardeberga	Dolerite		0.60 ± 0.01	3.27 ± 0.05	89	285 ± 4
71135 Hardeberga	Dolerite	Pyroxene, 71–100 μ	0.40 ± 0.01	2.13 ± 0.03	85	276 ± 4
71137 Rönnarp	Dolerite		0.69 ± 0.01	3.40 ± 0.05	78	259 ± 4
71138 Rönnarp	Dolerite		0.44 ± 0.01	2.43 ± 0.03	85	287 ± 4
71139 Rönnarp	Dolerite		0.36 ± 0.01	2.05 ± 0.03	86	298 ± 4
71139 Rönnarp	Dolerite		0.32 ± 0.004	1.55 ± 0.02	87	254 ± 4
71139 Rönnarp	Dolerite		0.11 ± 0.001	0.47 ± 0.001	49	232 ± 3
71140 Rönnarp	Dolerite		0.28 ± 0.004	1.55 ± 0.02	80	287 ± 4
71141 Rönnarp	Dolerite		0.19 ± 0.002	0.98 ± 0.01	87	271 ± 4
71160 Frualid	Vesicular diabase	Pyroxene, 71–100 μ	0.39 ± 0.01	1.96 ± 0.03	90	266 ± 4
71161 Frualid	Vesicular diabase		0.81 ± 0.01	4.22 ± 0.06	91	273 ± 4
71162 Frualid	Vesicular diabase		0.80 ± 0.01	4.22 ± 0.06	90	276 ± 4
71165 Tolånga	Melaphyre		1.19 ± 0.06	6.36 ± 0.09	97	278 ± 4
71185 Simrislund	Dolerite	Plagioclase, 71–100 μ	1.48 ± 0.02	7.88 ± 0.12	83	278 ± 4
71188 Petersborg	Dolerite		0.64 ± 0.01	4.58 ± 0.06	86	363 ± 5

Table 4. (cont.)

Sample and locality	Type of rock	Mineral concentrate and grain size	K, %	$^{40}\text{Ar}_{\text{rad}}$ mol/g $\cdot 10^{-10}$	$^{40}\text{Ar}_{\text{rad}}/^{40}\text{Ar}_{\text{total}}$ %	Age, Ma
71188 Petersborg	Dolerite	Plagioclase, 71–100 μ	1.30 ± 0.02	7.93 ± 0.11	88	314 ± 4
71189 Petersborg	Dolerite		0.67 ± 0.01	3.63 ± 0.05	79	283 ± 4
71190 Petersborg	Dolerite		0.69 ± 0.01	3.76 ± 0.05	90	282 ± 4
71193 Bollerup	Dolerite		0.54 ± 0.01	2.98 ± 0.04	84	286 ± 4
71193 Bollerup	Dolerite		0.58 ± 0.01	3.12 ± 0.05	85	280 ± 4
71193 Bollerup	Dolerite	Pyroxene, 71–100 μ	0.29 ± 0.004	1.54 ± 0.02	72	278 ± 4
71194 Röstänga mölla	Dolerite	Dolerite	0.60 ± 0.01	3.25 ± 0.05	84	281 ± 4
72034 Östraby	Dolerite		1.38 ± 0.02	8.44 ± 0.12	94	316 ± 5
73007 Torekov	Dolerite		0.78 ± 0.01	4.38 ± 0.06	88	293 ± 4
73009 Torekov	Dolerite		1.23 ± 0.02	6.96 ± 0.10	91	295 ± 4
73011 Odarslöv	Dolerite		0.39 ± 0.01	2.19 ± 0.03	89	291 ± 4
74190 Konga Klint	Dolerite		1.24 ± 0.02	6.46 ± 0.09	92	272 ± 4

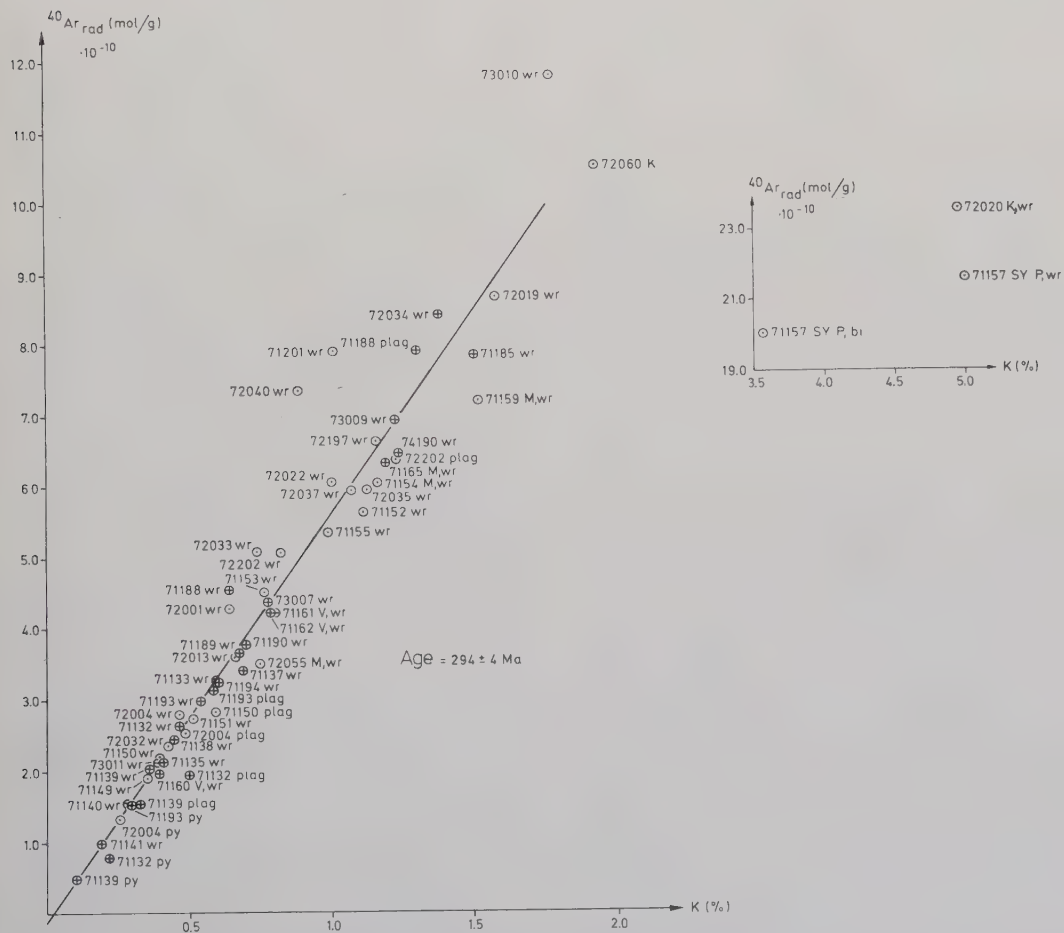


Fig. 7. K–Ar isochron diagram for the NW-striking dolerites and associated rocks. Intercept: -0.13 . MSWD: 4.79. $\oplus$ = dyke intersecting the Palaeozoicum. $\odot$ = dyke intersecting the Precambrian. M = melaphyre and augite porphyry. K = “kullaite”. V = vesicular diabase. SY P = syenite porphyry. wr = whole rock. plag. = plagioclase. py = pyroxene. bi = biotite.

system, and it is possible that the dolerite dykes have undergone a certain amount of argon diffusion.

A similar situation has been described from Liberia in West Africa (Dalrymple *et al.* 1975). Large and variable amounts of excess argon have been discovered there in dolerite dykes which intrude Precambrian rocks, while dykes of the same system intruding Palaeozoic sandstone are not seen to contain excess argon.

The excess argon in the dolerites which intrude Precambrian rocks is probably due to the fact that the Precambrian rocks have higher contents of radiogenic argon than Palaeozoic sediments. The hot basaltic magma released the argon by local heating of the bedrock, and this was then absorbed by the magma and retained in certain mineral lattices on crystallisation. Pyroxene, which is a main component of the sub-silicic rocks, is one of the minerals which easily absorbs excess argon and therefore affects the determinations. The age of the dolerites which intrude the Precambrian of Skåne can therefore not be calculated.

The samples which represent the dolerite dykes from the Palaeozoic bedrock are marked in Fig. 7 with crosses, to distinguish them from the samples which represent the dolerites of the Precambrian bedrock (marked by dots). Twenty-one samples from dykes which intrude the Palaeozoic were used to calculate the isochron age. An age of 294 ± 4 Ma was obtained.

The samples 71132 pyroxene, 71188, 71188 plagioclase and 72034 from the Palaeozoic region show differing ages. The cause of this may, in some cases, be argon diffusion in connection with local disturbances. Local variations are reflected, for example, in the three dates of the Petersborg dyke (71188–71190). The sample 71188 has an age (363 Ma) which differs markedly from the others, thus indicating the presence of excess argon in this sample. This conclusion presupposes that the lower age of the isochron is the correct age.

The NW.-striking dykes of Hardeberga, Rönarp and Dalby show lower K–Ar ages for the contact zones (71135, 71137, 71141, 71152) than for the central parts (71132, 71133, 71138, 71139, 71140, 71149, 71150, 71151). The fine-grained material of the marginal zones of a dyke do not retain argon as well as the coarser, central parts (Shafiquallah *et al.* 1970). The differences in age of samples taken across a dyke may also indicate that several intrusions have taken place within the one dyke. Heating in connection with a later intrusion can cause argon loss in the adjacent parts. No clear example of this phenomenon has been found in this investigation.

The plagioclase ages (71132 plag., 71139 plag.,

71150 plag., 71188 plag., 72004 plag. and 72202 plag.) are lower than the corresponding whole-rock dates. This is in agreement with the finding that plagioclase is a relatively poor argon-retainer (Dalrymple & Lanphere 1969). The pyroxene ages correspond to the whole-rock ages (71193 and 72004) or are lower (71132 and 71139). Differences in the mineralogical compositions of samples from the same dyke can cause differences in age, due to the varying abilities of the minerals to retain argon.

An explanation of the spread of the model ages has been sought in the chemical compositions of the samples. Chemical analyses of the contents of FeO, MgO, Na₂O, K₂O, MnO and H₂O⁺ have been carried out by Ingrid Johansson and Zoltan Solyom at the Geological Institute of the University of Lund. The samples investigated, however, show considerable chemical similarities, so that no explanation for the variations in K–Ar ages can be given.

The available K–Ar dates indicate a somewhat lower age for the melaphyres (71154, 71159, 71165) augite porphyrite (72055), vesicular diabase (71160–71162) and Kullaberg “kullaite” (72020) than for the NW.-striking dolerites, even though they do not form an isochron. Support for this statement is obtained from an actual field relationship seen in Hjelmqvist’s study of the Dalby quarry, where he discovered a “kullaite” which intruded into one of the NW.-striking dolerites (Hjelmqvist 1931, 1939). It is impossible to study the age relationship of the NW.-striking dolerites and the other rock types in the field.

The infillings of vesicles, both in the melaphyres and the vesicular diabase, may be a disturbing factor. Mankinen & Dalrymple (1972) describe the disadvantages of deposits with xenoliths, xenocrysts, vesicle- or vein-fillings and all the components which are not formed at the same time as the bedrock in general. Inclusions of younger material generally lower the analytical age of a rock. If the material contains inherited argon, the analytical age may, however, be too high.

The results available now correspond with the earlier datings of the Västergötland (Fig. 2) dolerite sills (282 ± 5 Ma, Priem *et al.* 1968, K–Ar) and the NW.-striking dolerites of Skåne (Upper Carboniferous, Mulder 1971, palaeomagnetism). Other proof that the sills of Västergötland are of the same age as the NW.-striking dolerites of Skåne is, however, lacking.

The palaeomagnetic pole determinations correspond to an Upper Carboniferous age for the dolerites and a lower, probably Permian age for the melaphyres (Bylund 1973, 1974). The paper by Printzlau & Larsen (1972) contains a statement

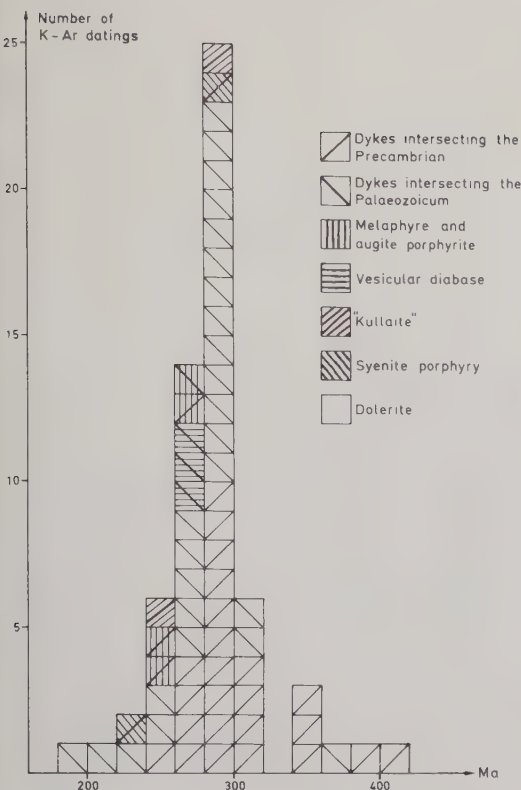


Fig. 8. Histogram of K-Ar data for the dykes in the NW.-SE. system.

concerning the age of the melaphyres in Skåne. It is suggested that they are of the same age as the basalts, that is, Cretaceous (Printzlau & Larsen 1972, K-Ar). This statement seems unlikely, in view of the present radiometric datings. The NW.-striking dolerites intrude into the Silurian schists but not the Triassic (Keuper) Kågeröd formation. According to the Geological Time Scale (Geological Society Phanerozoic Time Scale 1964), the interval between the formation of these two periods cor-

responds to the time 205–395 Ma ago. The isochron age of 294 Ma falls within this interval and corresponds to the Upper Carboniferous.

A final possibility to be considered, is whether the dykes of the Precambrian are really of a different age than those of the Palaeozoic. Intrusion could have begun earlier in the Precambrian area, while the majority of the dykes were intruded after the formation of the NW.-SE. fault system. Törnebohm & Hennig (1904) maintained that a certain difference in the grade of alteration exists in the dolerites in the Silurian area, as compared with those in the Precambrian. The Silurian rocks are softer, which may have been the reason for their greater alteration. Thin-section studies of the samples dated shows that the sericite alteration of the plagioclases, and the alteration of the pyroxenes to chlorite and serpentine, are similar for all samples. A difference in the grade of alteration has thus not been found, nor has any geological evidence been found which would indicate a difference in the ages of the NW.-striking dykes in the Precambrian and the Palaeozoic.

Shale

The purpose of dating the Silurian shale by the K-Ar method was to study the thermal effects on the retention of argon in the shales during intrusion of the dolerite dykes. K-Ar whole-rock age-determinations were therefore made on a total of nine samples of shale from Rönnparp and Odarslöv (Table 5). Ages of 259 Ma and 280 Ma respectively were obtained for shale samples taken 0.5 and 9 m from the dolerite dyke at Rönnparp, which corresponds approximately to the dyke's calculated age of 294 Ma. At a distance of 400 m, the age was 463 Ma. Argon loss has therefore occurred in the shale for a distance of at least 9 m from the dolerite contact at the time of intrusion of the 65-m-wide dyke. It is interesting to note that the model age of

Table 5. K-Ar data for Silurian shale intersected by NW.-striking dolerites.

Sample and locality	Distance from the dolerite m	K, %	$^{40}\text{Ar}_{\text{rad}}$ mol/g·10 ⁻⁹	$^{40}\text{Ar}_{\text{rad}}/^{40}\text{Ar}_{\text{total}}$ %	Age, Ma
72024 Rönnparp	0.5	3.20 ± 0.04	1.58 ± 0.02	92	259 ± 4
72027 Rönnparp	9	3.68 ± 0.05	1.97 ± 0.03	94	280 ± 4
73018 Rönnparp	400	2.65 ± 0.03	2.48 ± 0.04	91	463 ± 7
73020 Rönnparp	550	2.50 ± 0.03	2.07 ± 0.03	92	416 ± 6
73022 Rönnparp	1300	2.37 ± 0.03	2.11 ± 0.03	97	444 ± 6
73012 Odarslöv	10	2.03 ± 0.03	1.88 ± 0.03	95	459 ± 7
73013 Odarslöv	30	2.88 ± 0.04	2.01 ± 0.03	97	369 ± 5
73015 Odarslöv	70	2.22 ± 0.03	2.36 ± 0.08	96	519 ± 18
73017 Odarslöv	110	2.60 ± 0.03	2.52 ± 0.04	94	479 ± 7

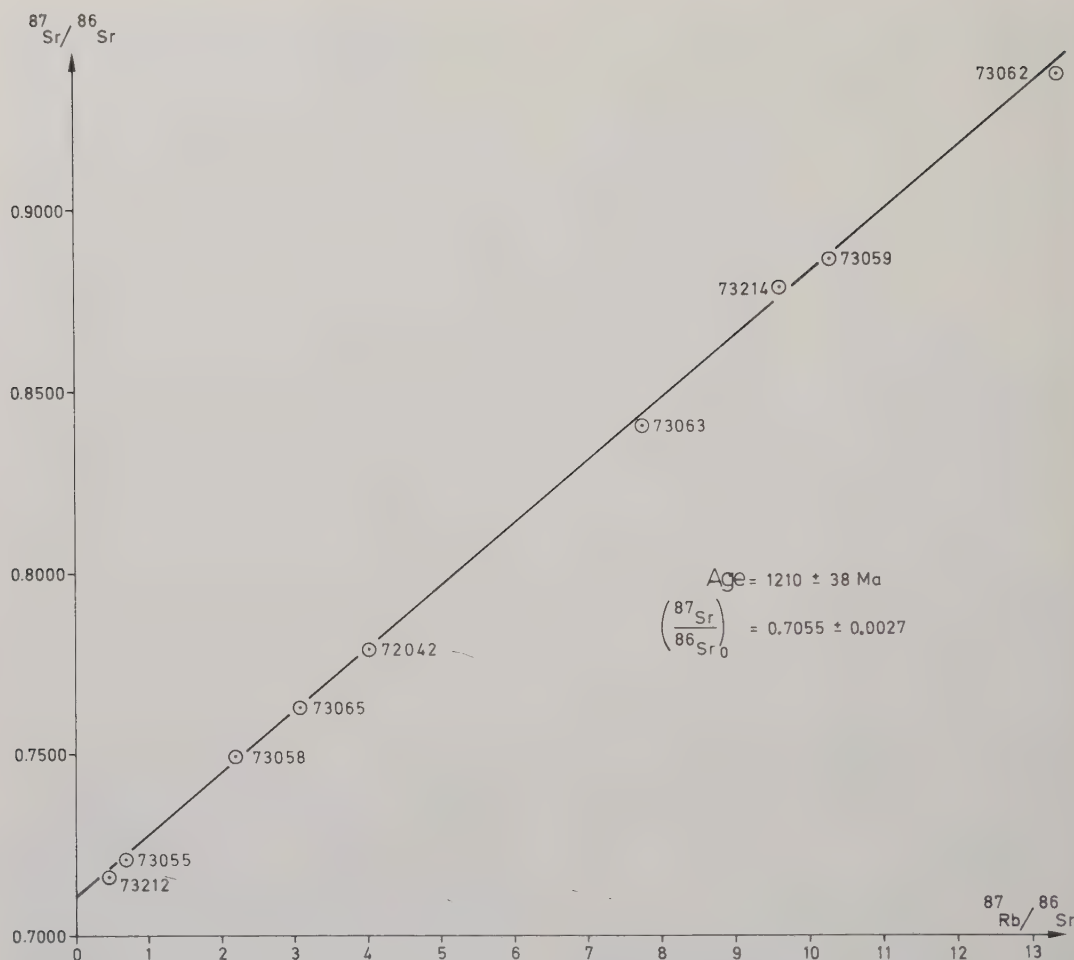


Fig. 9. Rb—Sr isochron diagram of whole-rock samples from the syenites.

the shale at a distance greater than 400 m from the dolerite contact is about 450 Ma, which is only slightly higher than the age indicated in the Phanerozoic Time Scale (Geological Society of London 1964) for the Ludlow.

The 25-m-wide dolerite dyke at Odarslöv has affected the host rocks for a distance of less than 10 m from the contacts. This is shown by the sample 73012, taken at 10 m, which has an undisturbed age.

The shale has been studied by X-ray diffraction. No differences in composition were noted between samples taken at various distances from the dolerite dykes. Hornblende and mica, which could be expected as a result of reheating (Hart 1964), were not found.

Syenites

The minimum age for the NNE.-striking dolerites is obtained by dating the syenites. A block, 1 m³ in size, and several smaller xenoliths of dolerite have recently been discovered during mapping by the Geological Survey of Sweden (Hugo Wikman 1974, pers. comm.) in Görbjörnarp (Fig. 3). This is clear field evidence that the dolerite is older than the syenite.

The syenite can best be studied in the quarry at Önnestad, where the whole intrusion is exposed. The marginal zone is thrust. The grain size of the various syenite intrusions is fairly uniform. They are medium- to coarse-grained and more or less dark grey in colour. The Aleholm syenite is somewhat richer in light minerals than the others.

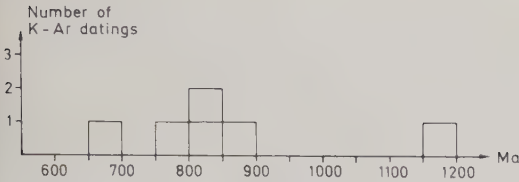


Fig. 10. Histogram of K–Ar data for the syenites.

Table 6. Rb–Sr data for the syenites.

Sample and locality	Rb, ppm	Sr, ppm	⁸⁷ Rb/ ⁸⁶ Sr	⁸⁷ Sr/ ⁸⁶ Sr (⁸⁶ Sr/ ⁸⁸ Sr = 0.1194)
72042 Brantaberg			4.032 ^a	0.7774 ^c
73055 Görbjörnarp			0.679 ^a	0.7197 ^c
73058 Görbjörnarp			2.204 ^a	0.7488 ^c
73059 Görbjörnarp			10.259 ^a	0.8859 ^c
73062 Önnestad			13.335 ^a	0.9337 ^c
73063 Aleholm			7.775 ^a	0.8396 ^c
73063	48.7	54.0	7.780 ^b	0.8391 ^d
73065 Brantaberg			3.099 ^a	0.7647 ^c
73065	44.8	91.2	3.106 ^b	0.7608 ^d
73212 Görbjörnarp			0.454 ^a	0.7168 ^c
73214 Görbjörnarp			9.642 ^a	0.8788 ^c

- ^aX-ray-fluorescence data. Standard deviation 0.5%.
^bIsotope-dilution analysis.
^cMass spectrometric analysis. Standard deviation 0.15%.
^dCalculated value.

Under the microscope, no differences are seen, except for a slight variation in the content of quartz. Thirteen Rb–Sr determinations were carried out on the material from nine syenite samples (Table 6). They form the isochron shown in Fig. 9. The isochron corresponds to an age of 1210 ± 38 Ma, all the points falling within the range of analytical error. The initial ⁸⁷Sr/⁸⁶Sr is 0.7055 ± 0.0027. Isotope-dilution analyses were carried out on two of

the samples (Table 6) as a check on the X-ray-fluorescence analyses of the ⁸⁷Rb/⁸⁶Sr ratio. Good agreement was obtained.

The K–Ar analyses of whole-rock syenite and separated minerals are presented in Table 7 and in the histogram (Fig. 10). The K–Ar dating of the syenites shows a varying degree of argon diffusion. The dating of sample 72042 hornblende is the only one which bears any relation to the relevant Rb–Sr isochron age. The results of the K–Ar dating in this investigation, like the palaeomagnetic dating by Göran Bylund (pers. comm.), give clear indications of a connection with the widespread thermal metamorphism in south-western Sweden 900 Ma ago.

Polkanov & Gerling’s K–Ar dating of the Vaggeryd syenite, which is referred to by Magnusson (1960a), shows an age that agrees with the results of the present Rb–Sr determinations of the Skåne syenites. However, a single K–Ar determination in a polymetamorphic area cannot be regarded as reliable. The determination published by Magnusson can therefore not be taken as evidence that all the syenites in the schistosity zone have the same age, even though it is plausible that the syenite intrusions, at least in the southern part of this zone, are of about the same age.

NNE.-striking dolerites

Samples of the NNE.-striking dolerites were taken from various localities in north-eastern Skåne and in Blentarp, Björnstorp and Romeleklint on the Romeleåsen horst. The NNE.-striking dolerites have thrust contacts, and the margins are altered to schistose amphibolite (Högbom 1910). This distinguishes them from the younger, unmetamorphosed, “bronzite diabases”, which also occur in the area, and with the same NNE. strike (Lundegårdh 1975, pers. comm.). The grain size of

Table 7. K–Ar data for the syenites.

Sample and locality	Mineral or rock type, grain size	K, %	⁴⁰ Ar _{rad} /mol/g · 10 ^{−9}	⁴⁰ Ar _{rad} / ⁴⁰ Ar _{total} %	Age, Ma
71171 Görbjörnarp	Syenite	4.45 ± 0.06	8.01 ± 0.12	93	810 ± 12
72038 Djurröd	Syenite	4.70 ± 0.06	9.27 ± 0.14	98	870 ± 13
72038 Djurröd	K-feldspar, 100–160 μ	4.55 ± 0.06	7.52 ± 0.11	97	754 ± 11
72042 Brantaberg	Syenite	4.72 ± 0.06	6.79 ± 0.10	98	672 ± 10
72042 Brantaberg	Hornblende, 71–160 μ	1.34 ± 0.02	3.88 ± 0.05	95	1176 ± 17
73061 Önnestad	Syenite	5.34 ± 0.07	10.14 ± 0.15	99	845 ± 12

Table 8. K-Ar data for the NNE.-striking dolerites.

Sample and locality	Mineral or rock type, grain size	K, %	⁴⁰ Ar _{rad} mol/g · 10 ⁻⁹	⁴⁰ Ar _{rad} / ⁴⁰ Ar _{total} %	Age, Ma
71166 Rumperöd	Dolerite, fine-grained	1.62 ± 0.02	4.16 ± 0.06	97	1070 ± 15
71168 Rumperöd	Dolerite, fine-grained	1.56 ± 0.02	4.27 ± 0.06	95	1124 ± 16
71170 Rumperöd	Dolerite, fine-grained	1.50 ± 0.02	4.03 ± 0.06	95	1109 ± 16
71173 Stora Björkeröd	Dolerite	1.07 ± 0.01	2.24 ± 0.03	94	916 ± 13
71174 Stora Björkeröd	Dolerite	1.08 ± 0.01	1.92 ± 0.03	91	802 ± 12
71174 Stora Björkeröd	Plagioclase, 160–200 μ	1.86 ± 0.02	3.51 ± 0.05	98	839 ± 12
71174 Stora Björkeröd	Pyroxene, 160–200 μ	0.87 ± 0.01	1.64 ± 0.03	94	839 ± 13
71175 Stora Björkeröd	Dolerite	1.04 ± 0.01	2.11 ± 0.03	94	889 ± 13
71176 Stora Björkeröd	Dolerite	1.18 ± 0.02	2.01 ± 0.03	94	776 ± 11
71177 Stora Björkeröd	Dolerite	1.04 ± 0.01	1.96 ± 0.03	91	837 ± 12
71178 Stora Björkeröd	Dolerite	0.96 ± 0.01	1.97 ± 0.03	96	899 ± 13
71179 Stora Björkeröd	Dolerite	1.11 ± 0.01	2.66 ± 0.04	99	1016 ± 15
71180 Hägghult	Dolerite	1.10 ± 0.01	2.45 ± 0.04	96	958 ± 14
71181 Hägghult	Dolerite	0.97 ± 0.01	1.87 ± 0.03	91	858 ± 12
71183 Hägghult	Dolerite	1.02 ± 0.01	2.09 ± 0.03	94	896 ± 13
71183 Hägghult	Plagioclase, 160–200 μ	1.24 ± 0.02	2.38 ± 0.03	96	852 ± 12
71183 Hägghult	Pyroxene, 100–160 μ	0.79 ± 0.01	1.56 ± 0.02	94	873 ± 13
72029 Blentarp	Dolerite	0.54 ± 0.01	1.58 ± 0.02	97	1190 ± 17
72031 Blentarp	Dolerite	0.57 ± 0.01	1.89 ± 0.03	94	1289 ± 19
72044 Balsberget	Dolerite	1.38 ± 0.02	2.45 ± 0.04	79	802 ± 12
72046 Bjärlöv	Dolerite	0.61 ± 0.01	1.79 ± 0.03	97	1179 ± 17
72058 Björnstorp	Dolerite	1.10 ± 0.01	3.78 ± 0.05	98	1329 ± 19
72059 Romeleklint	Dolerite	1.47 ± 0.02	6.36 ± 0.09	98	1565 ± 23
72194 Bjärahalla	Dolerite, fine-grained	1.29 ± 0.02	5.02 ± 0.07	94	1449 ± 21
72195 Bjärahalla	Dolerite, coarse-grained	0.71 ± 0.01	2.35 ± 0.03	95	1294 ± 19
72195 Bjärahalla	Plagioclase, 160–200 μ	0.71 ± 0.01	2.99 ± 0.04	96	1537 ± 22
72195 Bjärahalla	Biotite, 160–200 μ	1.71 ± 0.02	3.95 ± 0.06	93	984 ± 15
72196 Kårestad	Dolerite	0.48 ± 0.01	2.11 ± 0.03	97	1590 ± 23
72198 Brostorp	Dolerite	1.18 ± 0.02	1.69 ± 0.02	95	669 ± 10
72199 Rickarum	Dolerite	0.82 ± 0.01	1.38 ± 0.02	94	764 ± 11
72200 Assaretorp	Dolerite	1.35 ± 0.02	3.89 ± 0.06	96	1168 ± 17
72200 Assaretorp	Plagioclase, 71–100 μ	0.93 ± 0.01	2.67 ± 0.04	95	1169 ± 17
72200 Assaretorp	Biotite, 71–100 μ	5.91 ± 0.08	13.28 ± 0.19	95	966 ± 14
72208 Rickarum	Dolerite	1.06 ± 0.01	1.56 ± 0.02	96	685 ± 10
72208 Rickarum	Plagioclase, 160–200 μ	1.54 ± 0.02	1.80 ± 0.02	95	563 ± 8
72208 Rickarum	Hornblende, 160–200 μ	0.88 ± 0.01	1.71 ± 0.03	96	862 ± 13
72209 Rumperöd	Dolerite, coarse-grained	1.07 ± 0.01	4.23 ± 0.06	98	1470 ± 21

the dolerites varies between the different localities. The coarsest dolerites are found in Assaretorp, Bjärahalla and Rumperöd. The remainder are fine- to medium-grained. The variation in grain size is partly dependent on the width of the dykes. All the dykes exhibit chilled margins, which are more fine-grained than the central parts. The narrow dykes, such as one of the dykes at Rickarum (sample 72199 type), may have cooled so quickly that they

are homogeneously fine-grained. Grain size affects the ability of a mineral to retain argon, and thus the coarser dolerites, such as those at Björnstorp, Rumperöd (sample 72209 type), Bjärahalla (sample 72195 type) and Assaretorp exhibit relatively great ages. The fine-grained dyke (72194) at Bjärahalla, which has a greater age than the intersected, coarse-grained dolerite (72195) shows the existence of argon diffusion.

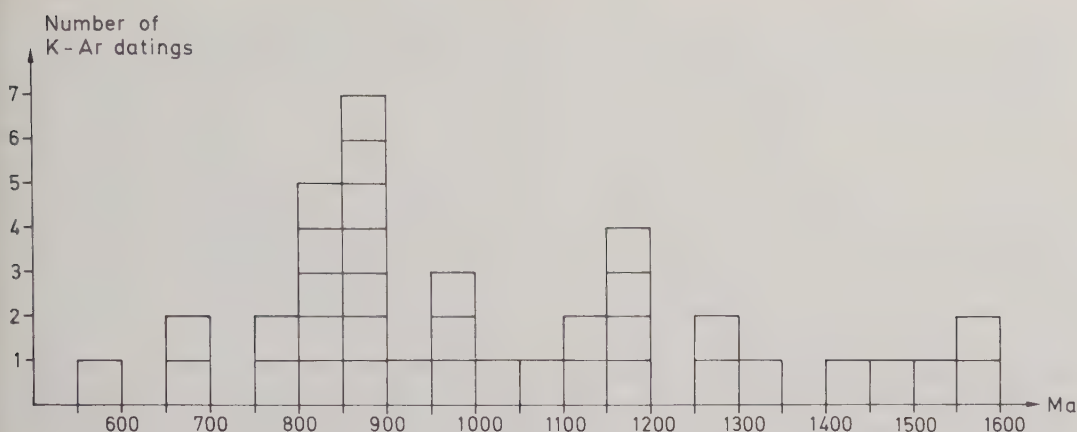


Fig. 11. The NNE.-striking-dolerite, K—Ar data shown in a histogram.

The number of K—Ar dates determined is 35. Most of them (25) were determinations on whole rock. A smaller number were made on separated minerals, such as plagioclase, pyroxene, biotite and hornblende. The results are to be found in Table 8 and in a histogram (Fig. 11). The ages vary between 563 Ma (72208 plagioclase) and 1590 Ma (72196). Five samples (72059, 72194, 72195 plagioclase, 72196 and 72209) have yielded ages (1565, 1449, 1537, 1590 and 1470 Ma) which satisfactorily correspond to the Rb—Sr isochron age. The other samples have lost argon by diffusion.

The Rb—Sr age (Table 9, Fig. 12) of 1600 ± 230 Ma (95 % confidence level) which was calculated on the basis of 14 samples, gives only an approximation of the age of the NNE.-striking dolerites. The high standard deviation (± 0.15 %) for the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio limits the possibility of dating these rocks. The initial ratio is 0.7033 ± 0.0015 .

A minimum age for the NNE.-striking dolerites is given by the syenite at Görbjörnar, which contains fragments of dolerite. These dolerite xenoliths probably originate from the nearby NNE.-striking dolerites, perhaps that at Rumperöd, only 750 m away. The fragments are sub-ophitic and have the same composition as the NNE.-striking dolerites (Hugo Wikman, 1975, pers. comm.). The calculated age of the syenite is 1210 ± 38 Ma. A maximum age is indicated by the new observation that the Karlshamn granite is intruded by a dyke belonging to the NNE.-striking dolerite swarm (Kornfält, 1975, pers. comm.). The age of the Karlshamn granite is approximately 1450 Ma (Welin & Blomqvist 1966, U—Pb, Larsen & Springer 1976, Rb—Sr). Presupposing that the interpretation of the geological observation by Kornfält is correct, this gives us the maximum age of the NNE.-striking dolerites.

Palaeomagnetic studies by Bylund (1975, pers. comm.) show considerable correlation between the remanent magnetism of the NNE.-striking dolerites and the syenites. From the position of the poles, an approximate age of 800–1000 Ma has been calculated for both rock types. It is possible that the palaeomagnetic dating reveals a phase in the activity of the schistosity zone.

The initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio for the NNE.-striking dolerites of 0.7033 ± 0.0015 corresponds to the data for sub-silicic rocks, 0.701–0.705 (Gast 1960), and they can be regarded as mantle-derived (Faure & Powell 1972). The somewhat higher value

Table 9. Rb-Sr data for the NNE.-striking dolerites.

Sample and locality	$^{87}\text{Rb}/^{86}\text{Sr}^a$	$^{87}\text{Sr}/^{86}\text{Sr}^b$ ($^{86}\text{Sr}/^{88}\text{Sr}=0.1194$)
71176 Stora Björkeröd	0.186	0.7071
71177 Stora Björkeröd	0.134	0.7056
71178 Stora Björkeröd	0.083	0.7056
71179 Stora Björkeröd	0.115	0.7058
72045 Bjärlöv	0.411	0.7125
72046 Bjärlöv	0.468	0.7114
72058 Björnstorps	0.909	0.7224
72195 Bjärahalla	0.034	0.7022
72196 Kärestad	0.275	0.7091
72199 Rickarum	0.501	0.7150
72200 Assaretorp	0.112	0.7035
72208 Rickarum	0.685	0.7178
72209 Rumperöd	0.087	0.7058
73315 Assaretorp	0.148	0.7080
73317 Assaretorp	0.097	0.7061
73323 Bjärlöv	0.813	0.7192
73325 Bjärlöv	0.771	0.7202
73328 Bjärlöv	0.977	0.7259
73330 Rickarum	0.585	0.7167
73332 Rickarum	0.821	0.7209

^aX-ray-fluorescence data. Standard deviation 0.5 %.

^bMass spectrometric analyses. Standard deviation 0.15 %.

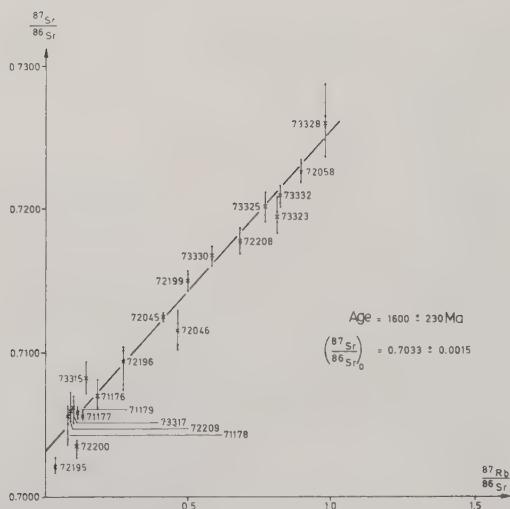


Fig. 12. Rb—Sr, whole-rock data for the NNE-striking dolerites plotted in an isochron diagram.

for the syenites, 0.7055 ± 0.0027 , may indicate a more complex development, but a more detailed discussion is not possible, due to the relatively high standard deviation.

Schistosity zone

A wide schistosity zone extends from southern Norway across the area between Lakes Vänern and Vättern to north-eastern Skåne (Fig. 2). The zone re-appears on the Romeleåsen horst in southern Skåne, after being covered by Palaeozoic and Mesozoic sediments in the central parts of Skåne. The schistosity zone, which strikes N.—S., divides southern Scandinavia into two parts. The Precambrian bedrock which is traversed by the schistosity zone consists mainly of granitic—granodioritic gneisses and subsidiary, greatly altered, supracrustal rocks. Within the schistosity zone, these rocks are crushed, schistosed and mylonitised. Karl-Axel Kornfält (1974, pers. comm.) describes the schistosity zone in the Kristianstad area as consisting of narrow, N.—S. to NNE.—SSW-striking schistose zones with undisturbed rocks between, where the primary E.—W. structures are preserved.

Many dolerite dykes and syenite massifs (dykes?) occur within the zone. They follow the direction of the N.—S., steeply dipping, schistosity planes. All the rocks of north-eastern Skåne are tectonically influenced (Mulder 1971) and most of them, except the dolerites and syenites, are traversed by the schistosity planes, which are characterised by sericite, biotite and epidote

(Magnusson 1960b). The thrust dolerites must be older than the youngest deformation. The occurrence and orientation of the dolerite dykes only within the schistosity zone indicate that their intrusion was made possible by the tectonic movements.

The Vaggeryd syenite lies in the western part of the schistosity zone near to the pre-Gothic gneisses in the west. It has been greatly affected by the tectonic movements. Intrusion of the syenite occurred in connection with movements along the schistosity planes and, according to Magnusson (1960a), it is of the same age as the schistosity. Quensel (1960) describes a locality at Röshult, 1.5 km N. of Vaggeryd, where the syenite cuts a hyperite (dolerite), and this corresponds to similar observations in north-eastern Skåne (see page 211).

The maximum age of the schistosity zone is given by the Småland—Värmland granites, which are seen to be influenced by the schistosity. The Småland granites are 1700—1750 Ma (Welin & Blomqvist 1966, Åberg, Rb—Sr, in preparation). K—Ar determinations indicate that movements within the zone continued until about 900 Ma ago (Table 8). Priem *et al.* (1968) and Mulder (1971) calculate the age of intrusion of the dolerites in the northern and central parts of the schistosity zone to be 1550 ± 100 Ma (K—Ar). The dykes in the southern part of the zone are characterised, according to the investigations of Priem & Mulder, by K—Ar ages around 800—900 Ma, clearly due to the regional thermal event in south-western Sweden.

The rocks of north-eastern Skåne and adjacent areas have probably been subjected to repeated deformation and metamorphism. The formation of the many pegmatites and granites in south-western Sweden 930—935 Ma ago (Magnusson 1960a, Welin & Blomqvist 1964, 1966) and the Bohus granite at 910 Ma (Skiöld 1976) also produced a thermal effect on the bedrock, and K—Ar age-determinations on biotite and muscovite samples from this area yield ages around 900—1100 Ma.

Thermal metamorphism is not necessarily the cause of the argon diffusion and the resulting, low, K—Ar, model ages of the NNE-striking dolerites and syenites. Alternatively, the rocks may have lain since their formation at a depth at which the temperature was too high for the argon system to close (Damon 1968). By uplift and cooling, a temperature was reached at which diffusion ceased.

The final uplift of parts of western Sweden occurred 950—1050 Ma ago or later. This is indicated by the distinct increase of K—Ar ages from 800—900 Ma to 1400—1500 Ma at the boundary with the granites of south-eastern Sweden. A more continuous decrease to the west would otherwise be expected (Welin & Blomqvist 1966).

At the time of deposition of the Dal formation, about 1100 Ma ago (Skiöld 1976), the area north of Lake Vänern was exposed. The whole of western Sweden has therefore not lain continuously at great depth since the schistosity zone was first established. In spite of this, rocks older than the Dal formation have ages around 900 Ma, and thus a later thermal metamorphism, during which intrusions of granite (Bohus) occurred, must have caused the final, powerful episode of argon diffusion in this part of western Sweden. A possible explanatory model for the common, 900-Ma, K—Ar ages for the bedrock of western Sweden must therefore be based upon a combination of block movements and a series of intrusion.

Conclusions

The radiometric age-determinations presented give an idea of the geological development within southern Sweden. A complete understanding of the history of the formation of the many basalts has not been attained. A larger number than the three dated must be studied to give a complete picture of the sequence of events. Two periods of eruptive activity can be tentatively distinguished, 108 Ma (Rallate and Lönnebjär) and 167 Ma (Göbnehall). The 167-Ma age is supported by a good isochron, while the 108-Ma age is more uncertain.

The K—Ar determinations give good results for rocks which have not been subjected to later alterations. No tectonic movements are thought to have affected the NW.-striking dolerites. The many K—Ar dates of these dykes clearly indicate an age of about 294 Ma, even though excess argon has affected the dating of the dolerites within the Precambrian area. The Colonus shale, which is intruded by NW.-striking dolerites, exhibits the effects of dolerite intrusion. The K—Ar system in the nearby parts of the shale was opened by intrusion and closed in connection with the cooling of the dolerites.

The final thermal metamorphism of the schistosity zone ended 800–900 Ma ago, at which time the argon system of the syenites and NNE.-striking dolerites definitely closed. This event is indicated by the K—Ar dates of the syenites and NNE.-striking dolerites, whose relevant ages were obtained by Rb—Sr dating. The syenites were intruded 1210 Ma ago and the NNE.-striking dolerites 1600 ± 230 Ma ago. These dolerites are probably slightly younger than 1600 Ma, as in the field they are shown to be younger than the Karlshamn granite originating 1450 Ma ago. The Rb—Sr dating indicates an age greater than 1370 Ma (1600 ± 230 Ma; 95 % con-

fidence level). A more definite minimum age for the formation of the NNE.-striking dolerites is obtained from the age of the syenites, as fragments of the dolerites have been found within the 1210-Ma-old syenites.

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A contribution to
PROJECT EAST EUROPEAN
PLATFORM (SOUTH-WESTERN BORDER)



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